Arid Zone Journal of Engineering, Technology and Environment. June, 2012; Vol. 8, 1-13

Print ISSN: 1596-2490, Electronic ISSN: 2545-5818
www.azojete.com.ng

DISTRIBUTION PATTERN ASSESSMENT OF A DUAL-PURPOSE DISC AGROCHEMICAL APPLICATOR FOR FIELD CROPS

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Abstract
A dual-purpose disc agrochemical applicator for field crops was developed to boost agricultural mechanization in crop production and also to overcome the safety concern of hazardous spray drift during agrochemical application by the field crop farmers. The dual purpose agrochemical applicator was mounted on a high clearance tractor and tested with respect to the granular fertilizer distribution patterns uniformity/liquid chemical uniformity of droplet sizes in spraying of the agrochemical. Results for NPK granular chemical indicated that, at low (50 kg/ha) and high (150 kg/ha) application rates with 550 rpm disc speed, distribution patterns skewed to the left whereas the distribution pattern at medium (100 kg/ha) application rates was good flattop. Also at high application rate with 1000 rpm disc speed, mean distribution pattern became poor (W-shape). For the liquid chemical herbicide HC 48 amine liquid, the mean values of volume median diameter (VMD) and number median diameter (NMD) were 108 µm and 80 µm at 90 lt/ha application rate at 5000 rpm rotary disc speed, and also 344 and 222 µm at 30 lt/ha application rate with 2000 rpm rotary disc speed. The mean values of coefficient of uniformity for droplet sizes expressed as VMD/NMD found in this study were in the range of 1.35 to 1.55 for HC amine 48 liquid chemical.

Keywords: Dual-purpose, disc, agrochemical, applicator, field crop

1. Introduction

Field crops like paddy rice are a typical feature of rice growing countries of East, South and South-eastern Asia. In those countries where rice is the staple food, agricultural mechanization is a very vital technique for boosting crop production. The concept of complete agricultural mechanization for rice production operations in an ideal rice field conditions was suggested by Abdul Rahman *et al*., (1994). One of the major problems of rice production is the shortage of labour resulting from the migration of rural dwellers to urban areas, making it very difficult for farmers to meet peak labour demands for paddy production (Chan and Cheong 1986). Meanwhile mechanization is needed to replace the labour which is not available or is very expensive. In Malaysia, like most developing countries of Southeast Asia, rice production power-intensive operations such as water pumping, land preparations, transplanting seedlings, harvestings and threshing are being mechanized but other operations like fertilizer and chemical (pesticides) applications are still performed with manually backpack conventional knapsack and motorized mist-blower sprayers which have many disadvantages. These include lack of uniformity of distribution applied to the crops, demanding high number of labour and drudgery in handling and loading of inputs on the field. Some common chemicals used in Malaysia for rice production include Paraquat, 2,4-D amine (2,4-dichlorophenoxy), endosulfan, atrazine, glyphosate, chlorpyrifos, tributyltin (TBT), urea, ammonium sulphate, calcium ammonium nitrate, superphosphates, ammonium phosphate, potassium chloride potassium sulphate and NPK. Fertilizer application and control of pests/diseases are still very much labour dependent even when conventional knapsack and motorized mist-blowers are used (Kanetani and Fauzi 1991).

2. Concepts of chemical application in agriculture

Application of granular fertilizers on agricultural fields is mainly performed using single or dual rotary disc (centrifugal) spreaders (Aphale *et al.*, 2003; Olieslagers *et al.*, 1996; Van Liedekerke *et al*., 2006; Van Liedekerke *et al*., 2009). Also centrifugal fertilizer spreaders spreading pattern is linked to machine characteristics (such as the rotational speed of the disc), particle properties and practical situations. The quality of the spreading pattern and evenness of the distribution is highly dependent on the implement settings. Pesticide application is mainly performed using conventional hydraulic nozzles. This is often highly inefficient with over 90% of the spray applied failing to reach the target area of the crop (Carlsen *et al.*, 2006; Matthews, 2008). But rotary atomizers produce a narrow range of drop sizes, 80% of which fall into the diameter range 50 to 137 µm at a volume median diameter (VMD) of 93 µm (Lefebvre, 1993). In the early 1980s, rotary atomizers were promoted to reduce herbicide application rates, but they were limited to unconfirmed testing (Pearson *et al*., 1981; Juste *et al.*, 1990).

Nowadays, there has been a growing concern about the environmental problems (such as air and water pollution and decline in biodiversity) associated with the application of mineral fertilizer and pesticides. For these reasons, accurate and uniform application of fertilizer/pesticides is absolutely important in minimizing environmental problems and costs. Over-doses can harm the environment seriously, as well as the crop itself. Consequently, the application methods of fertilizer/pesticides and the uniformity of the spread pattern have become important research topics in agricultural engineering. The high volume application methods used by some farmers to apply chemicals could result in higher costs compared to using low volume method and also the use of manually operated knapsack or backpack motorized mist-blower could cause fatigue to the farmers. Hence there is the need for the development of a machine that can improve agrochemical application for granular fertilizer and liquid pesticides to boost agricultural mechanization for field crops and also to overcome the safety concern of hazardous spray drift during chemical application by farmers. This paper presents the development and testing of new equipment that improves granular chemical distribution patterns and uniformity of liquid chemical spraying of agrochemicals.

3. Materials and methods

3.1 Design considerations

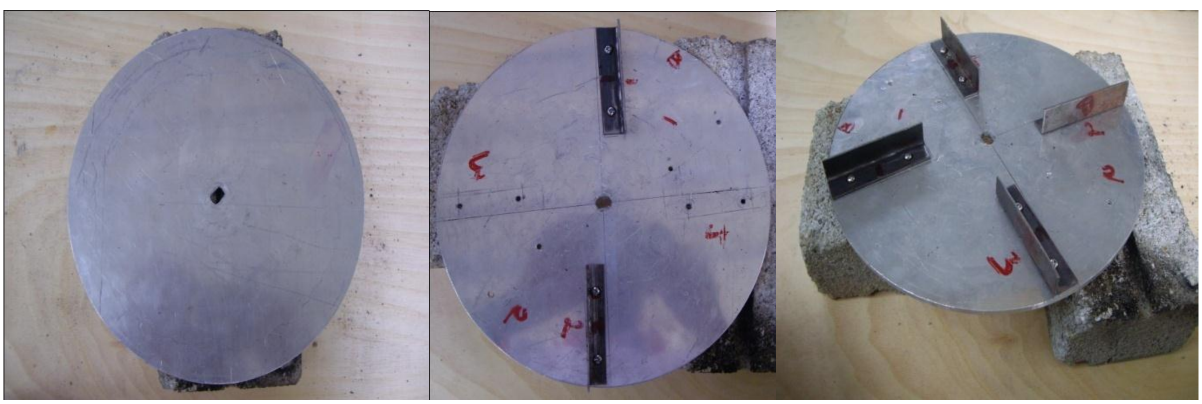
Rotary disc and chemical (granular and liquid) characteristics (cone angle, disc diameter, vane length, particle size, moisture content, density, viscosity, surface tension, coefficient of friction) were taken into consideration during the equipment development. The detailed procedures are as reported in Inn and Reece (1962) and Abubakar *et al.*, (2011). Tables 1 & 2 show the disc characterization dimensions for granular and liquid fertilizer application respectively. Figure 1 shows the three different discs used in both granular and liquid chemical applications.

Table 1: Disc's characterization dimensions for the granular chemical application

Disc parameter	Value
Disc type	Flat with vanes
Disc cone angle α (^{o})	0
Disc radius (mm)	250
Length of vane (mm)	120
Height of vane (mm)	10
Number of vane on a disc	2, 4
Type of vane	Straight

Table 2: Disc's characterization dimensions for the liquid chemical application

Disc parameter	Value
Disc type	Flat plane without vane
Disc cone angle α (^{o})	0
Disc radius (mm)	250



a) Flat plane disc (b) Flat with 2-vane disc (c) Flat with 4-vane disc

Figure 1: Discs used for both granular and liquid chemical application

3.2 Description of the machine/operation

The main features of the chemical applicator include the hopper, orifices, rotary discs, electric motor and the supporting frames (Figure 2). The applicator employs the use of two rotary discs rotating in opposite directions driven by 0.204 hp electric motors (TM80-15150). The rotational speed can be varied continuously from near zero to about 5000 rpm by means of a rheostat speed controller. Chemical materials (granular or liquid) inside the hopper fall freely by gravity through the orifices and drop directly on the rotating discs (impeller) and subsequently applied to the field. The disc is fitted with vanes for granular application and rotates at a speed of 550 to 1000 rpm, while for liquid application; a flat plane disc rotates at a speed of 5000 rpm and above to atomize liquid into fine spray. The centrifugal force of the rotary disc throws the material in an arc-like pattern over a distance to the right, front, and to the left.

Figure 2: Photograph of the dual-purpose disc chemical applicator

3.3 Performance test procedure

The chemical applicator distribution tests were conducted as recommended by ASAE Standard S341.4 (ASAE, 2009), method for measuring distribution pattern uniformity and calibration of granular broadcaster spreader using array of collection trays. Tests were conducted outdoor as it is the most representative of what performance is achievable in the field (Figures 3 and 4). A total of 36 transverse tests were conducted. Six tests each for both NPK granular fertilizer and HC 48 amine liquid chemical were carried out. Each test was repeated three times and the mean values were reported. The coefficient of variation (CV) for the transverse spread pattern is commonly used to ascertain an acceptable working width (swath) for the chemical applicator. The CV is the measure of the overall uniformity of the chemical application distribution pattern and was determined by overlapping the transverse distribution pattern at 1 m intervals working widths. Then the sample mean and standard deviation of the overlapped application rate were divided to determine the CV. The lower the CV, the more uniform the distribution pattern.

Figure 3: Arrangement of trays for granular fertilizer collection

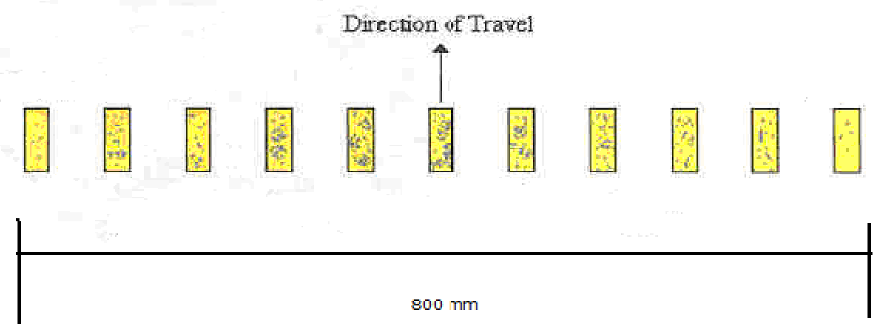


Figure 4: Arrangement of water-sensitive paper for spray droplet collection

Water-sensitive paper (WSP) was used in this study to evaluate the droplet sizes formed by the dual-purpose rotary disc chemical applicator. The water-sensitive paper images were captured using high resolution camera 1:1.4/12.5m (HF12.5HA-1B) after it was allowed to dry for 30 minutes and then scanned using Program FlexScan 2D (Figure 5). The percentage spray droplets cover, number of droplets per square centimeter, size distribution of droplets and volume/mass deposited, droplet density per unit area, the VMD and NMD of their spectrum on each paper were all estimated and analyzed using Matlab software program. The VMD and NMD of the spray droplet spectrum were determined to ascertain the spray characteristics. Before the experiment, the applicator was calibrated into three different flow rates for both granular and liquid chemicals. The openings of the orifices for the applicator were set at position low (50 kg/ha), medium (100 kg/ha) and high (150 kg/ha) for NPK granular fertilizer and low (30 l/ha), medium (60 l/ha) and high (90 l/ha) for HC 48 amine liquid chemical herbicide. These application rates were obtained from the adjusting of the chemical flow onto rotary discs by manually operated valves to achieve constant application rate and were deemed as typical target operator of the equipment (Aphale *et al.*, 2003). The disc rotary speed was set at 550 and 1000 rpm and 2000 and 5000 rpm for the granular liquid fertilizers respectively.

Figure 5: Equipment set-up for WSP image processing

3.4 Statistical analysis

All data were analyzed with completely randomized block design method using SAS 9.2 statistical software to identify statistical differences between the various combinations of equipment input parameters and the coefficient of uniformity as the output. Analysis of variance (ANOVA) was conducted for each of these inputs and output parameters and lastly differences between mean values were based on Duncan's multiple range tests (DMRT) at 95% confidence level.

4. Result and discussion

Tables 3 and 4 show the mean values of the coefficient of variation for the granular distribution uniformity and the volume median diameter for the liquid chemical. A CV of 18% was obtained at the overlapping transverse distance of 2.3 m and combinations of 550 rpm rotary disc speed and 100 kg/ha application rate (Table 3). The best liquid chemical coefficient of uniformity (CU) was obtained at the combinations of 5000 rpm rotary disc speed and 90 l/ha application rate (Table 4).

Table 3: Average values of coefficient of variation (CV) for the NPK granular chemical

Rotary disc speed (rpm)	Application rate (kg/ha)	Coefficient of variation (CV) (%)	Distance (m)
550	50	25	3.5
	100	18	2.3
	150	48	5
1000	50	28	4
	100	42	5
	150	72	7.5

Table 4: Average values of VMD, NMD, and ratio of VMD and NMD for HC 48 amine liquid chemical

Rotary disc speed (rpm)	Application rate (l/ha)	VMD (µm)	NMD (µm)	CU (VMD/NMD)
2000	30	344	222	1.55
	60	220	153	1.44
	90	186	122	1.52
5000	30	183	124	1.47
	60	137	94	1.45
	90	108	80	1.35

Results for the NPK granular fertilizer indicate that the mean distribution patterns varied in shape at three different application rates (Figures 6-9). Figure 6 shows the average distribution patterns shape at low, medium and high application rates. At low application rate, 2-vane disc and 550 rpm disc speed, the distribution pattern was skewed a little to the left hand side of the center line of the applicator. But at high application rates, 4-vane disc and 1000 rpm rotary disc speed, the distribution pattern shape becomes poor (W-shaped) (Figure 9), whereas the distribution pattern shape at medium rates, 2-vane number and 550 rpm rotary disc speed was flattop (Figure 6). Grift *et al.*, (2006) reported that the distribution pattern uniformity is also sensitive to some variations such as the increase in rotational speed of the disc. It was also observed that as the NPK application rate increased from low through the medium to the high, the distribution pattern changed from low left sided to a W-shaped pattern. Also, when the application rate increased together with increase of disc rotational speed, the distribution pattern changed from poor to worst. This revealed that for the combination of increase in disc rotational speed from 550 to 1000 rpm and increase in application rate from 50 to 150 kg/ha, the NPK distribution pattern change from normal flattop pattern to M-shape pattern. It was observed that, as the disc rotational speed was increased from low (550 rpm) to high (1000 rpm), the swath width also increased from 2.3 to 7.5 m (Table 3). This agreed with the findings of Aphale *et al.*, (2003) that the mean distribution width increased with increase in the disc rotational speed. This indicates that less materials than desired were applied at the center of the distribution pattern. The maximum spread distance of the granular NPK fertilizer at the three different application rates was ±4 m from the center line of the applicator and the effective swath width was 2.3 m.

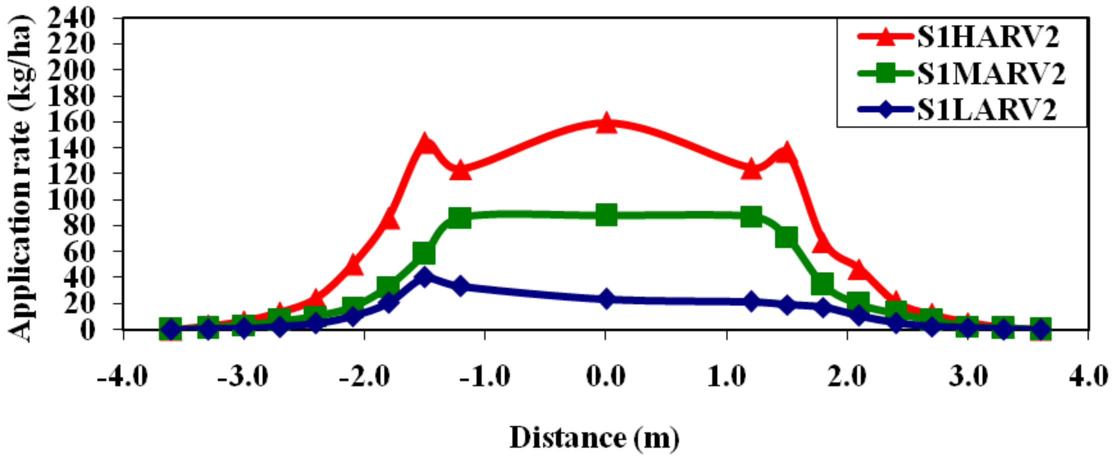


Figure 6: NPK granular fertilizer mean distribution patterns from three different applications, 550 rpm disc speed and 2-vane disc

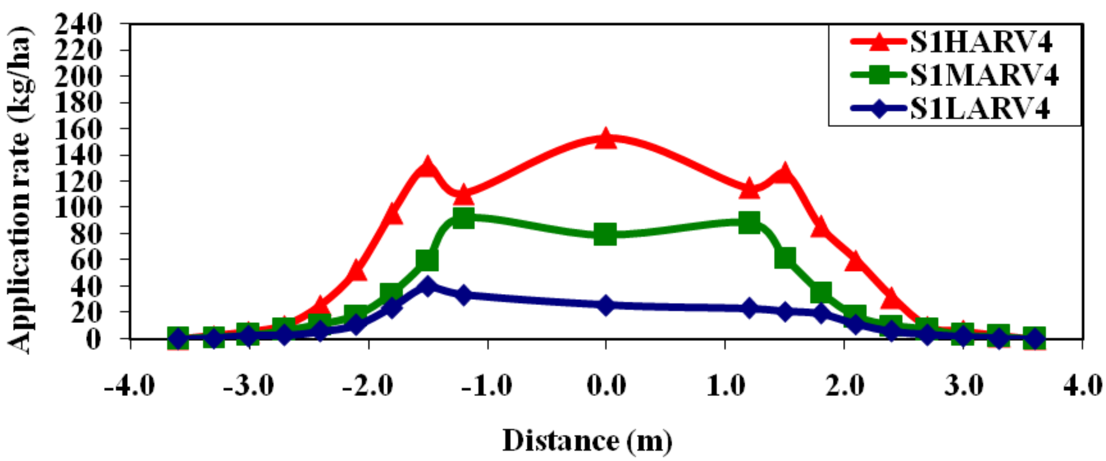


Figure 7: NPK granular fertilizer mean distribution patterns from three different applications, 550 rpm disc speed and 4-vane disc

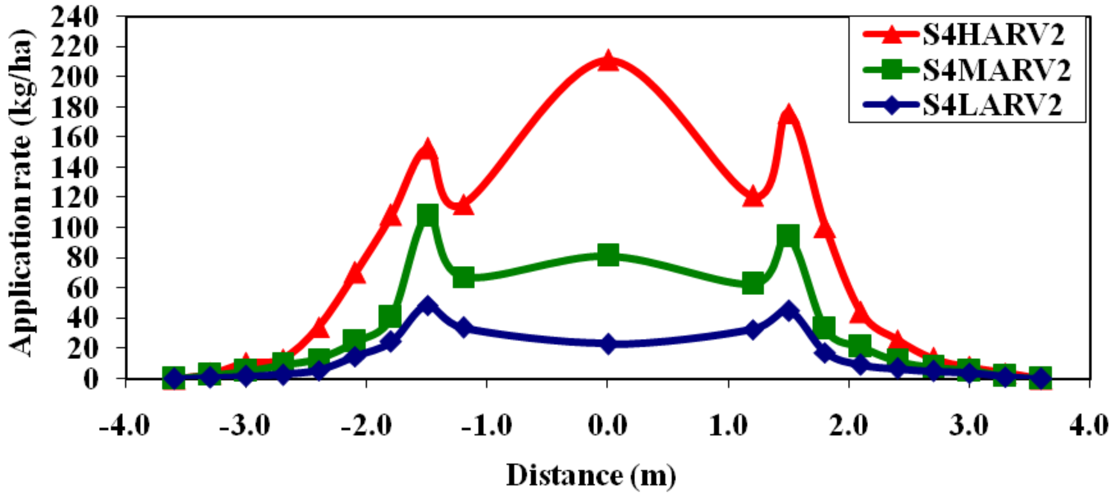


Figure 8: NPK granular fertilizer mean distribution patterns from three different applications, 1000 rpm disc speed and 2-vane disc

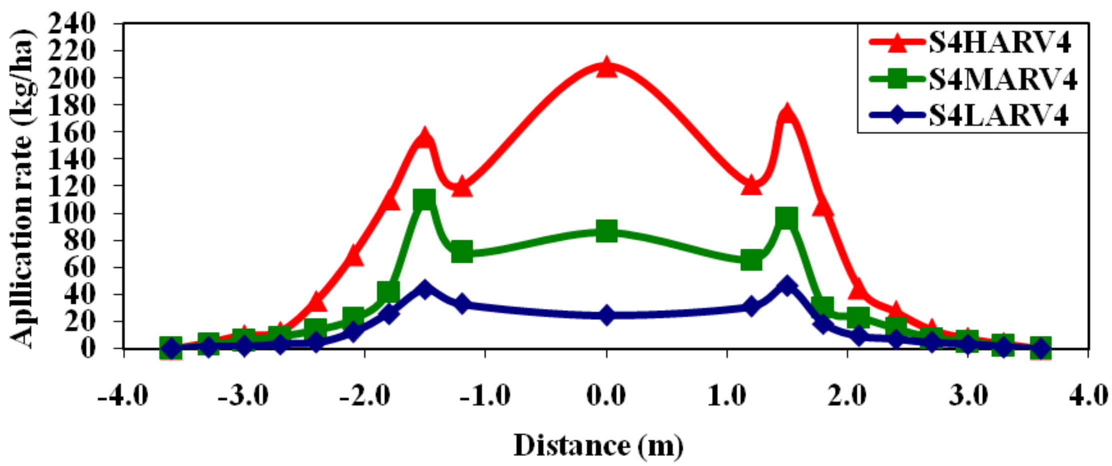


Figure 9: NPK granular fertilizer mean distribution patterns from three different applications, 1000 rpm disc speed and 4-vane disc

Key: S1 = Disc speed 1 = 550 rpm, S4 = Disc speed 4 = 1000 rpm, LAR = low application rate = 50 kg/ha, MAR = median application rate = 100 kg/ha, HAR = high application rate = 150 kg/ha, V2 = 2-number vane disc, V4 = 4-number vane disc.

Uniform distribution pattern with minimal irregularities was observed when NPK was applied at medium (100 kg/ha) application rate and 550 rpm disc rotational speed combined with 2-vane disc (Figure 6). Granular fertilizer application with rotary disc applicator involves some distribution pattern irregularities. These irregularities can be attributed to fertilizer material dynamics and shearing of the material mass. Other irregular distribution patterns are “W” and

"M" patterns. The "W" pattern has three areas of high fertilizer material concentration behind the applicator. The "M" pattern has little granular material behind the machine.

Figures 10 and 11 present the droplet size spectrums for HC amine 48 liquid chemical on the scanned WSP. At different values of liquid application rate, the average values of droplet volume median diameter (VMD) ranged from 108-344 µm at speeds of 5000-2000 rpm respectively. It was found that the volume median diameter (VMD) of the spray droplet decrease with increase in liquid flow rate and disc rotational speed. Smallest droplet volume median diameter (108 µm) was obtained at the highest application rate (90 lt/ha) and highest disc rotational speed (5000 rpm) for HC 48 amine liquid chemical. This finding is in agreement with the result obtained by Lefebvre (1993) who found droplet sizes of a rotary sprayer with VMD in the range of 120 to 300 micron to be most effective for liquid chemical application. This shows that the dual-purpose rotary chemical applicator converts more liquid into fine droplets in comparison with that reported for motorized flat fan pressure knapsack nozzle sprayers with 60-70% droplets larger than 250 µm.

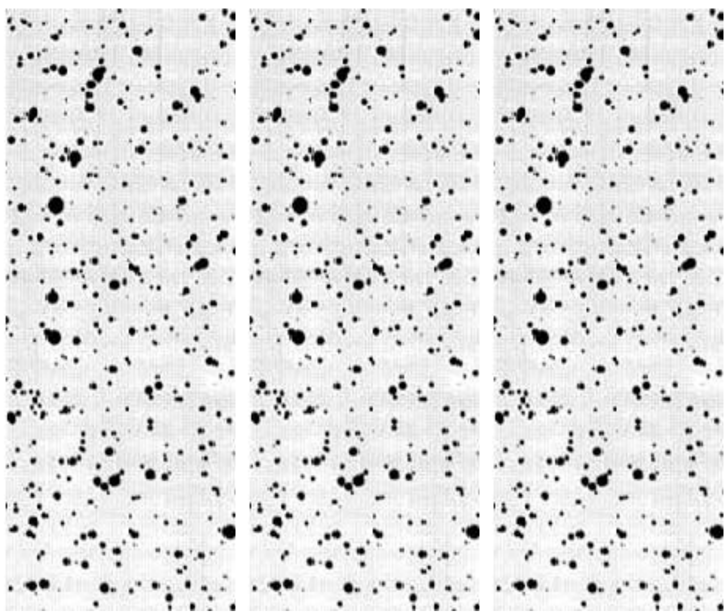


Figure 10: HC 48 liquid chemical spray droplet size at 2000 rpm disc speed, 30 l/ha application rate and 250 mm disc diameter that gives 344 VMD µm and 45 droplets/cm^2

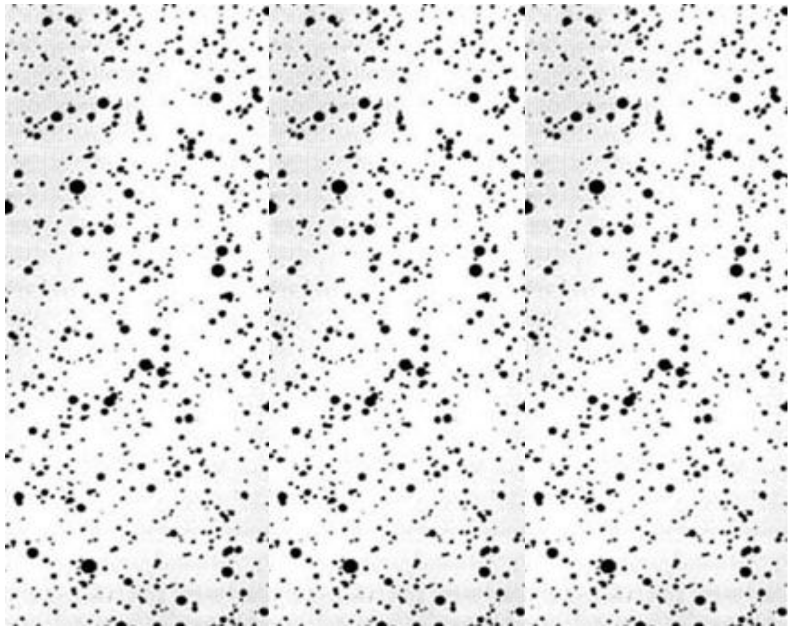


Figure 11: HC 48 liquid chemical spray droplet size at 5000 rpm disc speed, 90 l/ha application rate and 250 mm disc diameter that gives 108 VMD µm and 125 droplets/cm^2

The average values of coefficient of uniformity (expressed as VMD/NMD) for droplet sizes found in this study ranged from 1.35 to 1.55 for HC amine 48 liquid chemical (Table 4). The ratio of VMD and NMD (CU) gives the coefficient uniformity of the droplet spectrum; with values close to 1.0 as the more uniform the droplet spectrum and larger the value of CU gives wider the range of droplet sizes. This indicates that the spray droplet spectra obtained were more uniform when compared to the typical values of droplet size produced by both conventional knapsack and motorized mistblower sprayers with hydraulic pressure nozzles which ranged from 2.5 to 6.0 as reported by Ilham *et al.*, (2004). Furthermore, statistically, the effect of chemical flow rate and rotary disc speed was significant at $P < 0.05$ level at all combinations.

4. Conclusion and recommendations

The study concluded that the mean distribution patterns of granular fertilizer and droplet volume median diameter of a liquid chemical change with an increase of application rate and rotary disc speed. The average values of volume median diameter (VMD) obtained ranged from 108-344 microns at 90 lt/ha application and 5000 rpm rotary disc speed for HC 48 amine liquid chemical. Mean values of NPK granular distribution uniformity (CV) ranges from 18-72% at medium application rate and 550 rpm rotary disc speed. The dual-purpose equipment could be used to boost agricultural mechanization and also could be used for the application of both granular and liquid chemicals by the rice growers.

Acknowledgement

This study is classified under the Institute of Higher Learning Project, IHL (FRGS-Fundamental Research Grant Scheme) Project No 07-10-07-435FR. The authors are grateful to the authority of Universiti Putra Malaysia for granting the fund for the research project and the technical staff in the Department of Biological and Agricultural Engineering central workshop for their contribution and assistance during the development and testing of the equipment. Finally the assistance given by School of Graduate Studies is also appreciated for offering Graduate Research Fellowship (GRF).

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